Free-Floating Larvae of Crabs, Sea Urchins, and Rockfishes

Stephen R. Wing

Free-floating larvae of bottom-dwelling marine organisms play an important role in the ecology of the Gulf of the Farallones, both as the primary dispersal phase of several important species and in providing an important food source for many species, including salmon and seabirds. One of the greatest obstacles to understanding the population dynamics of organisms with free-floating larvae is a lack of knowledge of the mechanisms affecting larval dispersal and the resultant patterns of settlement before the larvae enter adult populations. This shortcoming hampers the prediction of a population's response to harvest and other stresses, and it remains one of the fundamental problems in studies of marine populations. Most exploited invertebrates and some fish populations are made up of fairly discrete sedentary adult subpopulations spread along a coastline. Together, these subpopulations form a network connected by larval dispersal. However, the mechanisms for transition from production of eggs, through the larval phase, to settlement, particularly the physical processes acting on the larval phase, are poorly known. For example, there are few data on invertebrates linking the number of adults in a population with the surviving number of first-year individuals. Environmental variation is generally a better predictor of yearly reproduction than adult stock size.

This lack of data is particularly nettlesome in the California Current System, where many commercially important coastal species, such as the Dungeness crab (*Cancer magister*), red sea urchin (*Strongylocentrotus franciscanus*) (fig. 1), and rockfish (*Sebastes* spp.) (fig. 2), have motile larval forms in the plankton during the spring. Thus, the motile larval phase is subject to the strong offshore and southward flow present during the spring upwelling season (see chapter on Current Patterns Over the Continental Shelf and Slope). For some time, scientists have been interested in how these species, and others with similar timing of reproduction, (1) maintain themselves at latitude and (2) are transported inshore into suitable juvenile habitat.

A field study was initiated in 1992 to understand how coastal oceanographic processes influence the delivery of crab larvae (fig. 3) and sea-urchin larvae to coastal populations around Bodega Head (lat. 38.2° N). The focus has been to determine what controls settlement of young in these species groups.

An extensive sampling program was organized, using both ships and shore stations; sampling extended over several years. This program has required cooperation from several agencies, including Gulf of the Farallones and Cordell Bank National Marine Sanctuaries, the U.S. National Marine Fisheries Service, the Scripps Institution of Oceanography, Point Reyes Bird Observatory, Oregon State University, the California Department of Fish and Game, and the Pacific Fisheries Environmental Group.

Results indicate that during periods of upwelling, invertebrate and rockfish larvae accumulate in the warm water that collects between the Farallon Islands and Point Reyes in the northern Gulf of the Farallones. Larval accumulation has also been noted in the upwelling shadows, or eddies, that form behind other capes and headlands when the north wind is blowing and surface water is moving in a southerly offshore direction. When the northerly winds that cause upwelling relax, this larvae-rich water moves north in buoyancy driven currents that remain coastally trapped as they move poleward. During this time many larvae that have been retained in the gulf are transported to the north and some settle out of the water column and onto the sea floor for their next life stage.

This pattern was demonstrated during 1994 and 1995 by shipboard surveys that sampled planktonic larval distributions and studied hydrography both south and north of Point Reyes during upwelling. Sampling was designed to determine whether high concentrations of crab larvae and rockfish larvae were retained in the Gulf of the Farallones. Data were collected during June 18 to 22, 1994, and June 15 to 19, 1995, aboard the U.S. National Oceanic and Atmospheric Administration (NOAA) research vessel *David Starr Jordan*. Shipboard sampling followed three 60-nautical-mile (nmi) transects parallel to shore at distances of 3 to 5 nmi (coastal), 25 nmi (shelf), and 50 nmi (oceanic) from shore. Several independent sites along each transect were sampled. Each site was sampled once during the day and once at night. The data obtained consisted of the contents of a plankton net cast to 70-m (230 ft) water depth, current profiles, and temperature and salinity profiles to the same depth. The ship also measured surface temperature and salinity continuously between stations. During the cruise, satellite images of the surface temperature patterns in the region were supplied to the ship from NOAA's CoastWatch Program and were used for directed sampling.

The upwelling jet seaward of Point Reyes and the upwelling shadow downwind (south) of the point were evident in both years from the velocity structure in the surface currents and the temperature and salinity of the surface layer. In both 1994 and 1995, we observed the frontal regions that marked the boundaries between four distinct water masses: (1) newly upwelled water, (2) oceanic water from offshore, (3) San Francisco Bay outflow, and (4) a mixture of these water types that was called "gulf water." The different fronts and water masses contained different types of larvae. In general, all stages of larval development for crabs of several species could be found within, but not outside, the gulf water. This water mass is found in the lee south of Point Reyes. In contrast, rockfish larvae were found in high concentrations offshore in oceanic waters and at the boundary between newly upwelled water and gulf water. The Gulf of the Farallones provides a pathway along which distinct pools of both types of larvae are likely to be transported to suitable juvenile habitat within the gulf and to the north.

Larval settlement becomes more episodic and less frequent with increasing northward movement away from the area of larval retention/accumulation south of Point Reyes. Weekly variation in upwelling leads to differences in annual settlement along the coast. Nearly twice as many crab larvae settle at Point Reyes and to the south, where warmer gulf water is constantly present, than to the north, where settlement occurs only when the northerly winds that cause upwelling subside and relaxation currents move northward. Sea urchin larvae also settle during specific oceanic conditions, but less predictably than crabs. In addition, the research suggests that consistent larval dispersal from any subpopulation of adult animals may be limited to the length of an embayment. For example, two such embayments on the northern California coast are from Point Reyes to Point Arena and from Point Arena to Cape Mendocino. Because strong seaward currents set up at each end of these embayments during upwelling, larvae caught in these currents would be swept out to sea and have no chance of developing and becoming a part of the adult population.

The data collected in this study of the distribution of free-floating larvae in the Gulf of the Farallones provide critical information on the lifecycles of commercially important bottom-dwelling species. This information is crucial to the effective management and conservation of coastal marine ecosystems in the gulf.

Further Reading

Botsford, L.W., Quinn, J.F., Wing, S.R., and Brittnacher, J.G., 1993, Spatial management of a benthic invertebrate, the red sea urchin *Strongylocentrotus franciscanus*: Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations, Alaska Sea Grant College Program Report 93-02.

Botsford, L.W., Wing, S.R., and Largier, J.L., 1998, Population dynamic implications of larval dispersal in meroplanktonic populations, *in* Pillar, S.C., Moloney, C.L., Payne, A.I.L., and Shillington, F.A., eds., Benguela dynamics—Impacts of variability on shelf-sea environments and their living resources: South African Journal of Marine Science, v. 19.

Morgan, L.E., Wing, S.R., Botsford, L.W., Lundquist, C.J., and Diehl, J.M., 2000, Spatial variability in red sea urchin (*Strongylocentrotus franciscanus*) cohort strength relative to alongshore upwelling variability in northern California: Fisheries Oceanography, v. 9, p. 83-98.

Quinn, J.F., Wing, S.R., and Botsford, L.W., 1993, Harvest refugia in marine invertebrate fisheries—Models and applications to the red sea urchin, *Strongylocentrotus franciscanus*: American Zoologist, v. 33, p. 537-550.

Wing, S.R., Botsford, L.W., Largier, J.L., and Morgan, L.E., 1995, The spatial structure of relaxation events and crab settlement in the northern California upwelling system: Marine Ecology Progress Series, v. 128, p. 199-211.

Wing, S.R., Botsford, L.W., and Quinn, J.F., 1998, The impact of coastal circulation on the spatial distribution of invertebrate recruitment, with implications for management, *in* Jamieson, G.S., and Campbell, A., eds., Proceedings of the North Pacific Symposium on Invertebrate Stock Assessment and Management: Canadian Special Publication of Fisheries and Aquatic Sciences, v. 125, p. 285-294.

Wing, S.R., Botsford, L.W., Ralston, S.V., and Largier, J.L., 1998, Meroplanktonic distribution and circulation in a coastal retention zone of the northern California upwelling system: Limnology and Oceanography, v. 43, no. 7, p. 1710-1721.

Wing, S.R., Largier, J.L., and Botsford, L.W., 1998, Coastal retention and onshore transport of meroplankton near capes in eastern boundary currents, with examples from the California Current, *in* Pillar, S.C., Moloney, C.L., Payne, A.I.L., and Shillington, F.A., eds., Benguela dynamics—Impacts of variability on shelf-sea environments and their living resources: South African Journal of Marine Science, v. 19, p. 119-127.

Wing, S.R., Largier, J.L., Botsford, L.W., and Quinn, J.F., 1995, Settlement and transport of benthic invertebrates in an intermittent upwelling region: Limnology and Oceanography, v. 40, p. 316-329.

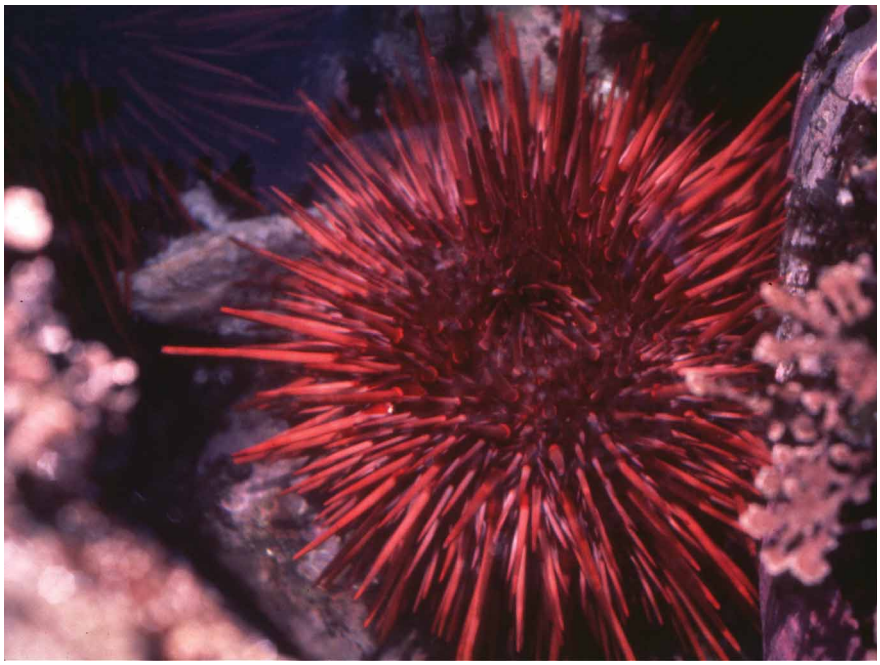

Figure 1. Red sea urchins, harvested for sushi, are one of many commercially important coastal species in the Gulf of the Farallones with swimming larval forms that drift as plankton during the spring. (Photograph from Gulf of the Farallones National Marine Sanctuary.)

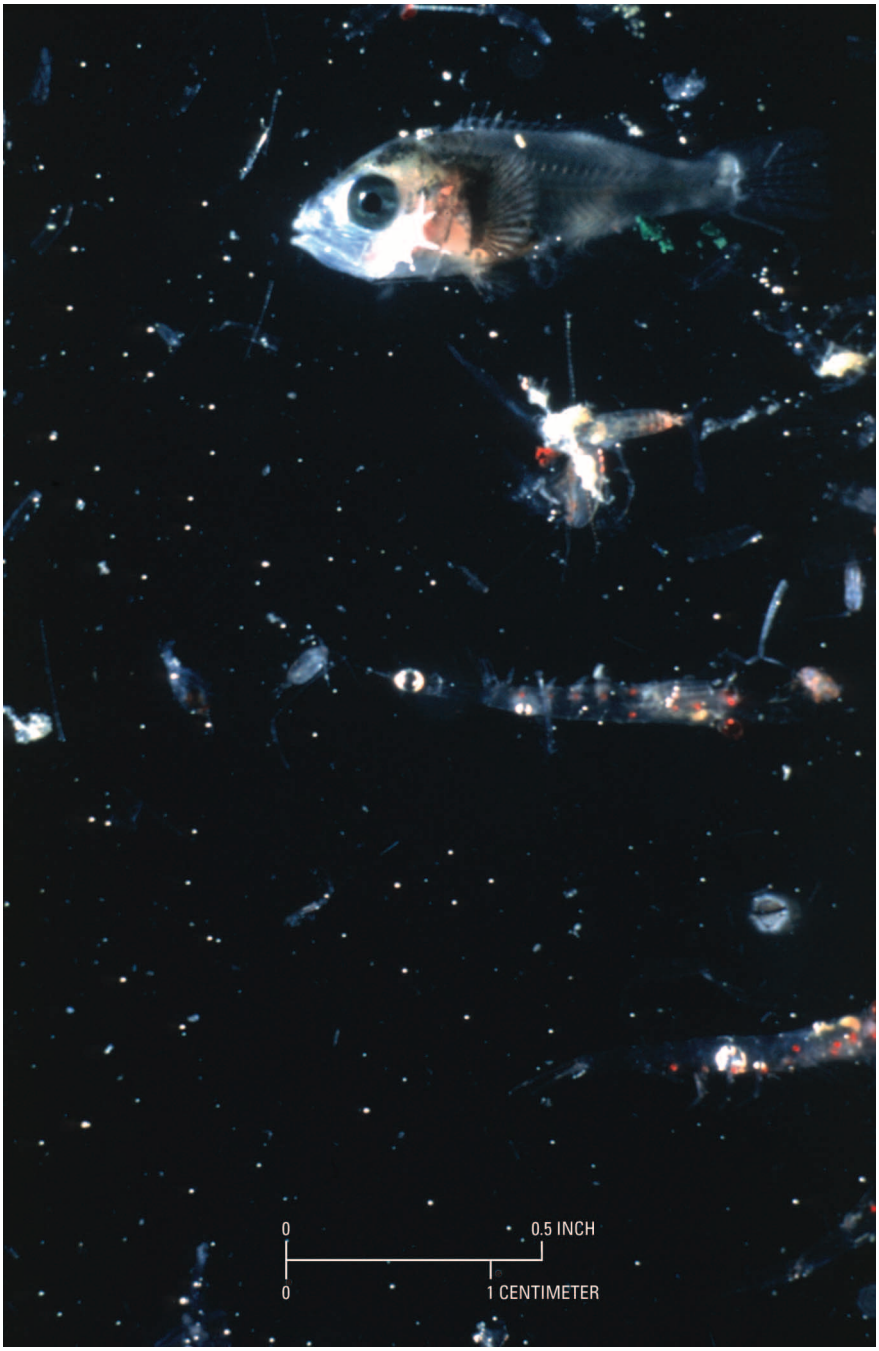

Figure 2. Sample of plankton collected in the Gulf of the Farallones, showing a larval rockfish, euphausiid shrimp (krill), and other zooplankton. (Photograph from Gulf of the Farallones National Marine Sanctuary.)

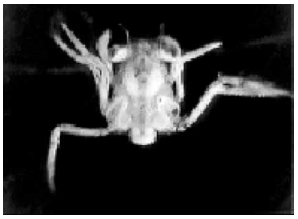

Figure 3. Larval crab from the Gulf of the Farallones, greatly magnified.